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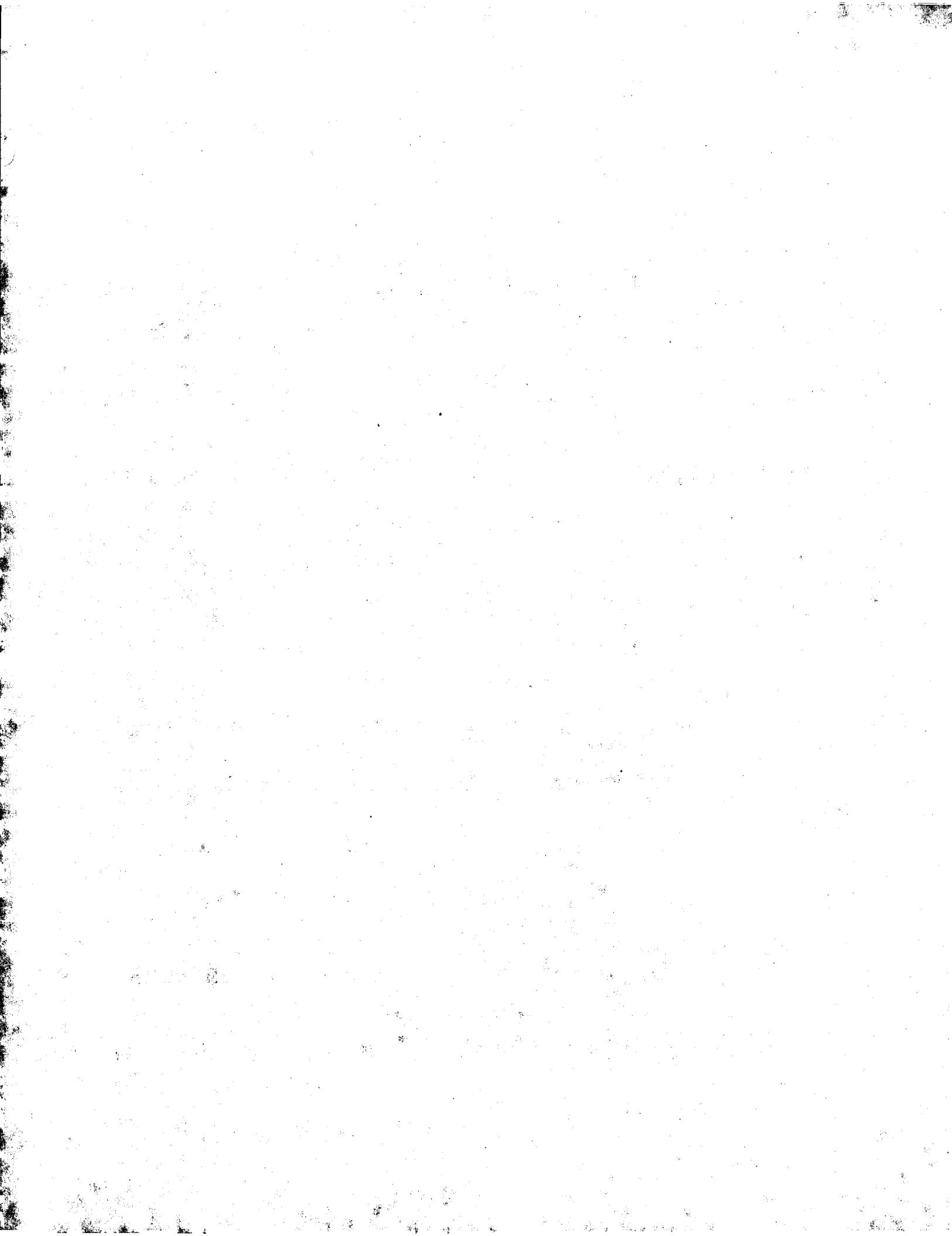
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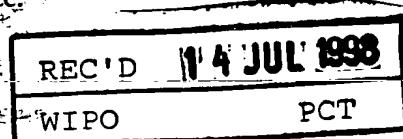
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Specification and Drawings, as originally filed, with Application for Patent Serial No:  
2,202,716, on April 15, 1997, by THE UNIVERSITY OF WESTERN ONTARIO,  
assignee of De Lasa Hugo, for "Photocatalytic Reactor and Method for Destruction of  
Organic Air-Borne Pollutants".

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# PHOTOCATALYTIC REACTOR AND METHOD FOR DESTRUCTION OF ORGANIC AIR-BORNE POLLUTANTS

## FIELD OF THE INVENTION

The present invention relates to reactors for the control of pollutant emissions from manufacturing facilities and more particularly, to a novel photocatalytic reactor and method for the destruction of volatile organic air-borne pollutants.

## BACKGROUND OF THE INVENTION

Chemical plants and manufacturing facilities are a source of air pollutants especially petrochemical plants which frequently emit air-borne pollutants. A need exists for the control of pollutant emissions at chemical plant sites. While environmental regulations have been put in place in order to significantly limit the level of emitted air-borne pollutants, such regulations create operating constraints for existing refineries, pulp and paper mills, manufacturing facilities and chemical plants. One approach towards pollution abatement at such chemical plant sites is to manage or control the "source of emission" by various mechanisms.

The purification of water and air using photocatalysts is one promising methodology of the so-called advanced oxidation processes. This process utilizes  $TiO_2$  (anatase) as the photocatalyst of choice due the fact that it is insoluble, non-toxic, has a powerful oxidizing ability, it can be excited with solar light and it is readily attachable to various types of supports. The possibilities for photocatalytic technology is very impressive given the minimum energy cost, or essentially zero energy cost when solar energy is employed for powering the photoreactors. Potential applications for photocatalytic reactors cover the degradation of a wide spectrum of impurity levels contained in the air as well as in industrial waste water and potable domestic water.

Carey et al (1976) were among the first to utilize  $TiO_2$  for the photocatalytic degradation of pollutants and reported that, by using a light beam with a wave length of 365 nm, it was possible to achieve complete degradation of chloro-organic molecules in water. Near UV irradiated  $TiO_2$  can also be applied very effectively for the photoconversion of organic air-borne pollutants (Holden et al, 1993). Various organic molecules such as alkanes, alkenes, alcohols, aldehydes and aromatics have all been found susceptible to this treatment. In the case of non-chlorinated compounds, no intermediate products have been observed with pollutants being completely converted to carbon dioxide. For chlorinated compounds, chlorine and phosgene have also been observed (Holden et al, 1993). While results for photocatalytic degradation of pollutants are encouraging, several aspects of the technology, including catalyst activity, activity decay with time-on-stream and catalyst regeneration are still to be derived and optimized(Luo and Ollis, 1996, Jacoby et al, 1996).

While some of the basic principles for photocatalysis are relatively well understood, the design of suitable photoreactors for achieving high energy efficiency and complete photoconversion of intermediates remain a subject of debate. Photocatalytic reactors for air borne pollutants involve specific approaches for supporting the photocatalyst and specific choices for photoreactor configurations. Three main choices are reported: a) Entrapment of  $TiO_2$  in a glass mesh (Al-Ekabi et al, 1993), b) support of the  $TiO_2$  in coated tubes (Ibushki et al, 1993) and in honeycombs (Suzuki, 1993) and c) holding  $TiO_2$  in a ceramic membrane (Anderson et al, 1993). While the designs quoted in b) and c) are of limited applicability for large volumes of gases, the use of  $TiO_2$  embedded in a fiber glass mesh is an option that may offer considerable potential. In this respect, a photocatalytic reactor based on this principle was reported by Al-Ekabi et al, 1993. This unit utilized an impregnated mesh with  $TiO_2$  "enwrapped" on an emitting light source of a photoreactor. In this

reactor, several layers of the mesh cover the emitting source. This method and reactor had several intrinsic limitations such as a lack of a secure degree of  $TiO_2$  loading in the crystalline "anatase" form and the lack of intimate or uniform contact of the evolving fluid (i.e. polluted air) with the mesh. Finally, 5 only a very limited fraction of the immobilized  $TiO_2$  was being irradiated.

It is apparent that to succeed with the use of photocatalysis for oxidizing impurities, several issues must be still addressed as stated by Yue (1985a and 10 1985b), such as the selection of proper illumination for a given geometrical reactor configuration and the provision of adequate flow and mixing characteristics inside the reactor and the light-catalyst interaction. It is therefore an object of the present invention to provide an advantageous and novel photocatalytic reactor suitable to process different types of air streams containing various amounts of volatile organic carbon pollutants which 15 obviates at least one of the problems and shortcomings encountered using known photocatalytic reactors and the prior art methods.

## SUMMARY OF THE INVENTION

In accordance with the present invention, there has been developed a novel catalytic photoreactor and method for the destruction of organic air-borne pollutants, the photoreactor being characterized by one or more of the following 20 aspects:

the photoreactor has a means for the admission of a gas stream carrying air-borne volatile organic carbon pollutants;

the photoreactor has at least one mesh section homogeneously loaded with  $TiO_2$  for irradiation; and

the photoreactor has at least one Venturi section for constraining the gas stream towards a smaller diameter and increasing gas velocity directed at the mesh section in order to be photocatalytically oxidized and degraded; and  
a mechanism to divert the treated air stream outside the photoreactor.

5 The photoreactor may additionally include a mechanism to recycle the treated gas stream back through the reactor. Additionally, the photoreactor may be designed to allow air streams to pass through without any photocatalytic treatment.

In accordance with another aspect of the present invention, there is  
10 provided a catalytic photoreactor method for the destruction of organic air-borne pollutants, the method comprises the steps of:

- passing a gas stream having volatile organic carbon pollutants therein through a photoreactor in which the gas stream is constrained towards a smaller diameter and its velocity increased and directed at a mesh section  
15 homogeneously loaded with  $TiO_2$  for irradiation of the pollutants.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

A detailed description of the preferred embodiments is provided herein below with reference to the following drawings in which

Figure 1 is a side elevational view of the catalytic photoreactor in  
20 accordance with the preferred embodiment of the present invention;

Figure 2 is a side elevational view of the Venturi section of Figure 1;

Figure 3 is a sectional view through lines A-A of Figure 2;

Figure 4 is a sectional view through lines B-B of Figure 2;

Figure 5 is a sectional view of the mesh area of Figure 2;

Figure 6 is a sectional view through lines C-C of Figure 5;

Figure 7 is a perspective view of the catalytic photoreactor of the invention called the PHOTO-CREC-AIR REACTOR™;

5 Figure 8 shows the irradiation density on the mesh at various positions in the reactor;

Figure 9 shows the uniform gas velocity distribution in the reactor;

Figure 10 is an overview of the PHOTO-CREC-AIR REACTOR components; and

10 Figure 11 is a temperature programmed desorption curve showing complete water desorption from the mesh in the reactor.

In the drawings, preferred embodiments of the invention are illustrated by way of example. It is to be expressly understood that the description and drawings are only for the purpose of illustration and as an aid to understanding  
15 and are not intended as a definition of the limits of the invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The novel catalytic photoreactor of the present invention, referred to as the PHOTO-CREC-AIR apparatus, is illustrated in Figure 1. The reactor is configured with a number of changes in diameter or cross-section. These  
20 transitions in diameter are required to implement a photoreactor where lateral and focused illumination of each of the mesh sections are optimized. With this design and considering the transparent mesh cloth selected 100% of the TiO<sub>2</sub> loaded into the mesh will be irradiated. Another feature of the apparatus is related with the positioning of the glass mesh. The glass mesh (Mesh Section)

is transversely positioned with respect to the air stream carrying the organic pollutants. High mass transfer rates are, thus, achieved.

To obtain smooth changes of gas flow directions without abnormal flow patterns or flow upsets, a Venturi is incorporated in the design. As seen better 5 in Figure 2, this Venturi constrains the gas stream progressively towards a small diameter with minimum disturbance and a significant increase in gas velocity and reduction in pressure. The gas stream leaving the Venturi section is directed such that it impinges at high velocity and with a controlled and uniform pattern on the homogeneously illuminated mesh section.

10 The new photocatalytic reactor has the following components:

Focused illumination and light reflectors. These are window sections located in the lateral areas: transition section between the Venturi and Mesh Sections (Figure 1). Pairs of UV lamps, light reflectors and windows allow irradiation of the Mesh Target Areas. Given the window angle (close to 7° 15 from vertical axis) and beam focusing, irradiation of both sides of the mesh and nearly 100% of the  $TiO_2$  are secured. Figure 8 reports mesh irradiation in a prototype of the Photo-CREC-Air apparatus. It is shown that mesh irradiation is very uniform and in a level of  $35 \mu\text{watts/cm}^2$  which represents not less than 22% of the incoming irradiation.

20 Venturi Section. The Venturi section provides a reduced cross-sectional area and a geometrical configuration for achieving high gas velocity, reduced pressures (suction pressure and adequate mesh illumination). All this is accomplished forming a flow structure with minimum waking and flow upsets. The suction pressure provide flow conditions close to the windows with 25 minimum particle adhesion on the antistatic glass and minimum, light losses on the window near region during extended operation.

Impinging Gas Stream. As a result of the Venturi section, a well developed gas stream impinges upon the mesh section at a preselected controlled position. With these high gas velocities, high mass transfer rates and consequently high photoconversion rates are achieved in the impregnated  $TiO_2$  mesh.

Mesh Section. The Mesh section has a circumferential area (target mesh) and is supported from the external wall of the duct (standard tube). This mesh succession has dimensions allowing maximum illumination and contains high density glass mesh screens embedded with  $TiO_2$  particles (e.g. 50 wt %).

The embedding of  $TiO_2$  particles is achieved as follows: a) addition of 0.1 g of dry  $TiO_2$  on the mesh surface (10 cm diameter), b) addition of a controlled amount of solved (e.g. 20% of the acetone required for incipient wetness of the glass mesh). This helps migration of  $TiO_2$  particles from the surface towards the inside the mesh. Once the impregnated mesh dried, particles are held very strongly to the structure of the mesh with no particle losses and this even under high gas flow velocities (e.g. 3 m/s). The procedure can be repeated several times until 50 wt % of  $TiO_2$  in the mesh is achieved.

The mesh is supported on a perforated plate providing uniform gas flow contacting and mechanical strength. The size of the openings of the perforated plate, supporting the fibre glass mesh, is carefully chosen (e.g. 8.3 mm) to provide proper pressure drops across the hot plate and desired flow patterns. These significant pressure drops avoid gas maldistributions and inefficient contacting between the gas stream and the fibre glass mesh holding the  $TiO_2$ . Figure 9 provides an example of uniform gas flow distributions in the near plate region with radial velocities in the 3.5 m/s range. Glass mesh properties, which includes electrostatic forces and mesh transparency, secure maximum loading

of  $\text{TiO}_2$  minimum catalyst entrainment by the gas stream and high  $\text{TiO}_2$  particle irradiation.

Heated Plate supporting the Glass Mesh - Fibre glass mesh (high efficient pleated air filter) with optimum  $\text{TiO}_2$  loading is supported in a heated plate. A pair of heaters provide the heat supply to carefully control the temperature in the heated plate ( $100 +/- 2.5^\circ \text{C}$ ). The use of a heated plate prevents adsorption of water in the fibre glass mesh and consequently, any eventual  $\text{TiO}_2$  deactivation.

It was also demonstrated, using TPD (Temperature Programmed Desorption) (Figure 11) that at  $110^\circ \text{C}$  water is desorbed completely from the fibre glass mesh. Consequently, the use of a heated plate should allow water resulting from the reaction or the humidity in the stream to be desorbed from the mesh and a result not affecting the photocatalytic reactor performance. As well heating the glass plate provides higher photoconversion rates and consequently higher performance of the Photo-CREC-Air.

For example, it was demonstrated that the heated plate holding the mesh can be operated at  $100^\circ \text{C}$  level with temperature differences in the plate varying within a  $+/- 2.5^\circ \text{C}$  only.

### Example 1

One prototype of the Photo-CREC-Air apparatus (10 cm diameter) was manufactured at Mechanical Shop, UWO, assembled and tested at the CRE-UWO (Figures 1 and 7 to 10). In this unit, experiments with model pollutants at various concentration levels are currently under way. Reactants and product including various intermediates are being measured and identified. This novel unit with the configuration proposed (Mesh section, Venturi section, Windows,

Reflector, Focused Illumination) is uniquely suited for destruction of organic pollutants in gaseous streams.

In summary, the novel photochemical reactor of the present invention is designed for the oxidation of air-borne organic pollutants. The unit has an 5 optimum configuration in terms of flow patterns, as it provides for intimate and controlled contact of the flowing air stream with TiO<sub>2</sub>. The photoreactor also provides for high loading of TiO<sub>2</sub> particles on the supported mesh and a maximum use of light energy resulting in an optimum illumination of the mesh.

This photocatalytic reactor can be brought on stream for emergency 10 situations in a matter minutes. It is specially suited to deal with undesirable conditions caused by chemical leaks into air streams in chemical plants. The system is also conceived as a rugged design and is able to deal with hot and dusty gases.

Although preferred embodiments of the invention have been described 15 herein in detail, it is understood by those skilled in the art that variations may be made thereto without departing from the spirit of the invention or the scope of the appended claims.

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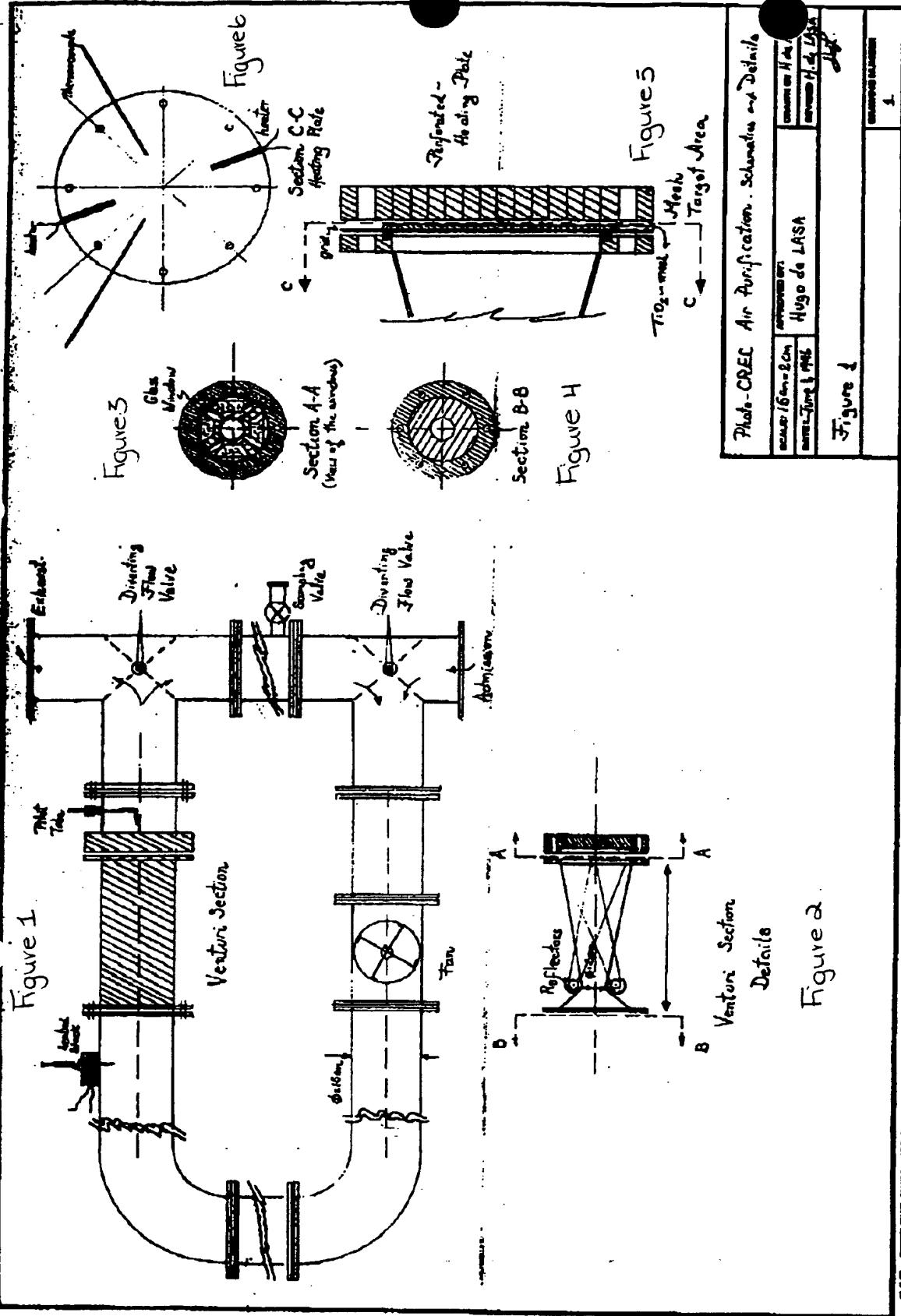
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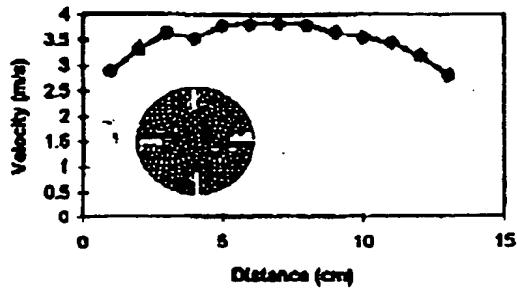


Figure 9 Gas velocity at 2° from the last plate at 55°C  
( $\pm 2.5^\circ\text{C}$  difference between T1 & T2)

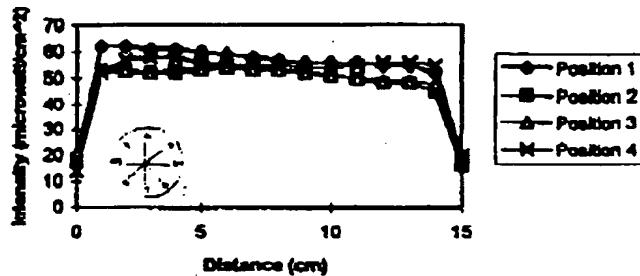


Figure 8 Intensity (intensity/cm²) = the much at various position (P1,P2,P3,P4)

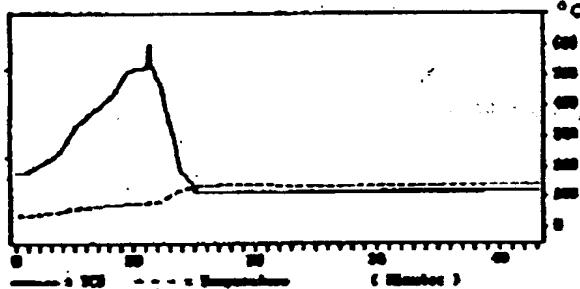


Figure 11 TPD showing complete desorption from week of 115°C



Figure 10 Overview of Photo-CREC-Air components. a)perforated plate, b)supported mesh with  $\text{TiO}_2$  c)Reflectors for illumination.

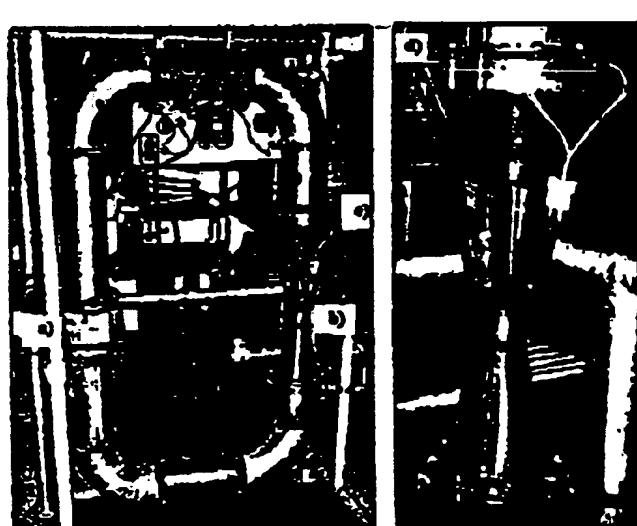


Figure 7 Overview of the photo. CREC Air reactor for 140 (CFM-STP).  
a) gas blower, b) Venturi Section, c) last plate with mesh,  
d) blow-out of venturi with windows

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